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Development of a Mathematical Pendulum Experimental Modeling Tool Based on Proximity Sensors for Video Tracker Analysis

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Abstract: Physics has an important role in the development of science and technology today. Physics phenomena can be observed through experiments using research instruments. One of the interesting physics phenomena is simple harmonic motion on a mathematical pendulum. Observations show that the experimental data of the mathematical pendulum is only limited to the oscillation time and the number of swings. In addition, the instruments used are still manual. The solution to overcome these problems is to use a proximity sensor-based mathematical pendulum experiment modeling tool and video analysis using a tracker. The purpose of this research is to determine the accuracy and precision of the mathematical pendulum modeling tool experiment, knowing the effect of changes in rope length on the period and frequency of the mathematical pendulum modeling tool. The type of research used is design and development (Research and Development). Data collection is done in two ways, namely direct and indirect measurements. Direct measurements were made by varying the length of the rope on the mathematical pendulum experiment modeling tool. Indirect measurements were taken to determine the accuracy and precision of the proximity sensor-based mathematical pendulum modeling tool. The results of the data analysis obtained are displayed in the form of tables and graphs. Based on the data analysis, three research results can be stated. First, video analysis using a tracker obtained a sinusoidal graph.

Keywords: Modeling Tool, Simple Harmonic Motion, Proximity Sensor, Tracker Video Analysis

1. Introduction

The development of Science and Technology (IPTEK) has progressed very rapidly in the current era of globalization. The advancement of science and technology requires a science to be dynamic and develop in accordance with the dynamics of life [1]. Physics is one of the branches

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of science that contributes to the development of technology today. Physics has an important role in the advancement of science and technology in line with the development of today's increasingly sophisticated human needs [2]. Physics is one of the branches of science that studies the phenomena that occur in the universe and their interactions. Physics is referred to as the basis or foundation of technology [3]. Learning physics is not enough to be obtained by reading or listening to explanations alone. Studying physics is closely related to experiments. This is because in studying physics required proof of the theory, concepts, laws and rules of physics [4]. Through experiments various phenomena and basic laws in physics can be proven. Experimentation is one part of the stages of the scientific method that has an important role in testing a phenomenon that occurs. Experimental activities are usually carried out by researchers both in education and industry.

In the world of education, experiment-based student-centered learning models are one of the strategic and innovative choices. By conducting experiments, students are able to know the process and symptoms of a phenomenon and to prove the justification of the theory [5]. In the industrial sector, experimentation is one of the right frameworks to use. Experimental results can be used as a reference for the system to be worked on, so that optimal production results are obtained. The development of technology is an important factor in the success of current experimental activities [6]. The use of technology makes experiments more extensive in collecting sufficient evidence, so as to reduce uncertainty before launching a product. The use of digital technology in experimental activities can be in the form of integration in the system built, monitoring processes and results, processing and storing data, to the publication of experimental results [7].

Experimental activities are carried out and arranged in such a way that they can represent the physical phenomena that are being observed to appear like the actual conditions. Along with the passage of time, the development of science and technology has been able to produce various research instruments that are precise and practical. In conducting an experiment, what is needed is a tool or instrument. Instruments are tools used to collect, process, analyze and present research data systematically [8]. One of the physical phenomena that is often experimented is simple harmonic motion on a mathematical pendulum. The instrument used in this experiment consists of a load hanging from the end of a rope with a certain height. The load is made in an equilibrium condition and then given a deviation angle of θ. Furthermore, the load will be released, because the restoring force makes the load move harmoniously. The simple harmonic motion that occurs in a mathematical pendulum can be observed directly [9].

Simple harmonic motion is the alternating motion of an object through a certain equilibrium point with the number of vibrations of the object in each second is constant [10]. Harmonic motion causes objects or mechanical systems to oscillate through an equilibrium point. The restoring force acting on the system is proportional to the relative position of the system mass to the equilibrium point and is always directed towards the equilibrium point [10]. Some previous researchers have conducted research on simple harmonic motion. Research in 2019 conducted by Yani entitled Making a Mathematical Pendulum Modeling Tool with Automatic Rope Length Control for Video Tracker Analysis. This research uses a stepper motor programmed using Arduino Uno as a rope length controller. The limitation of this research is that in determining the number of oscillations and the time of oscillation of the pendulum is still done manually, namely using a stopwatch, and the release of the load from the starting point is still done manually, namely assisted by the practitioner.

Another research in 2020 conducted by Octaviandari & Sucahyono with the title Development of Learning Media for Simple Harmonic Motion Material to Improve the Science Process Skills of Students in Class X. This research uses sensors to determine the oscillation time automatically. The limitations of this study are determining the length of the rope which is a variable that affects the value of gravitational acceleration and many pendulum oscillations are still measured manually. Further related research in 2022 conducted by Syarifuddin et al entitled Design of Harmonic Motion Props in the Form of Mathematical Pendulums Using Arduino-Based Photodiode Sensors. This research utilizes photodiode sensors in mathematical pendulum props. The weakness of this research is that the length of the rope varies and the measurement of the length of the rope is still manual, and the data reading still varies so that it is less practical and prone to measurement errors which cause discrepancies in the data obtained with the theory.

In real conditions, the solution is still considered inadequate and still requires optimization of experimental activities. The creation of a simple harmonic motion experimental system on a mathematical pendulum related to this research is based on the shortcomings and weaknesses of previous research. The system is expected to be able to adjust the length of the rope and the number of oscillations automatically as desired. This tool uses sensors that have higher sensitivity than previous research. This is an added value of this mathematical pendulum simple harmonic motion experimental system so that its use is more effective and efficient. Experimental data on this tool will be displayed on the LCD, namely data on period, frequency, acceleration of gravity and oscillation time. Therefore, researchers are interested in conducting research with the title "Development of a Proximity Sensor-Based Mathematical Pendulum Experiment Modeling Tool for Video Tracker Analysis".

2. Materials and Method

This research is classified into design and development research (Research and Development). Hasan (2003) defines that for design and development research as "a disciplined investigation conducted in the context of developing a product or program for the purpose of improving either the thing being developed or the development". Hevner et al (2004) specialized the definition of information systems domain by defining "the design science of creating and evaluating IT (Information Technology) artifacts intended to solve identified organizational problems". Richey and Klein (2007) specified the educational domain definition by defining this type of research as: "the systematic study of the design, development, and evaluation process with the goal of establishing an empirical basis for the creation of instructional and non-instructional products". The stages in the design and development research model are identifying the problem behind the research, describing the objectives, designing and developing the tool, testing the tool, evaluating the research results, communicating the test results. .

Block diagram design is the most important thing done in making a proximity sensor-based mathematical pendulum experiment modeling tool. The block diagram contains electronic designs that will greatly affect the performance and final results of the proximity sensor-based mathematical pendulum modeling tool. The block diagram geometry arrangement of the proximity sensor-based mathematical pendulum modeling tool can be seen in Figure 1.

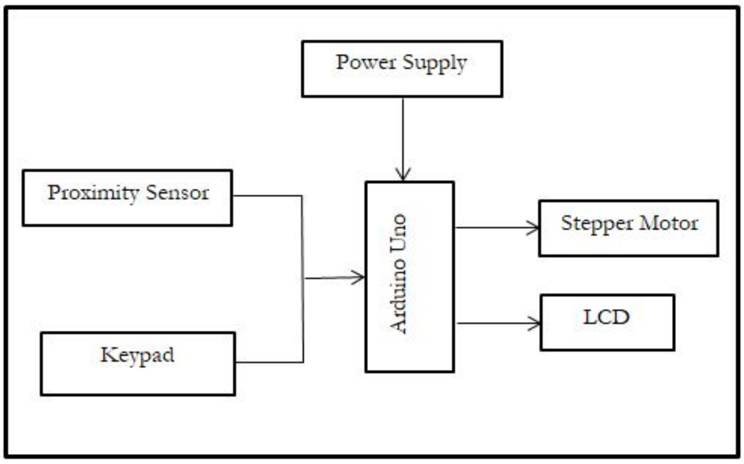

Figure 1. Block diagram of the electronics
for the creation of the mathematical pendulum modeling tool

The block diagram of the proximity sensor-based mathematical pendulum modeling tool consists of power supply to supply electricity to the components. The proximity sensor functions to determine the oscillation time, period, frequency, and gravitational acceleration when the pendulum oscillates. Stepper motor is used to open and roll the rope that works based on the program inputted to Arduino Uno. LCD (Liquid Crystal Display) serves to display the data obtained when the pendulum oscillates. Keypad as place to input data that will be programmed using Arduino Uno.

Block diagram design is the most important part in making a mathematical pendulum modeling tool. The detailed design of the proximity sensor-based mathematical pendulum modeling is in the form of mechanical design and software design. This mathematical pendulum modeling tool uses a stepper motor to control the length of the rope used. The mechanical design of the proximity sensor-based mathematical pendulum modeling tool is shown in Figure 2.

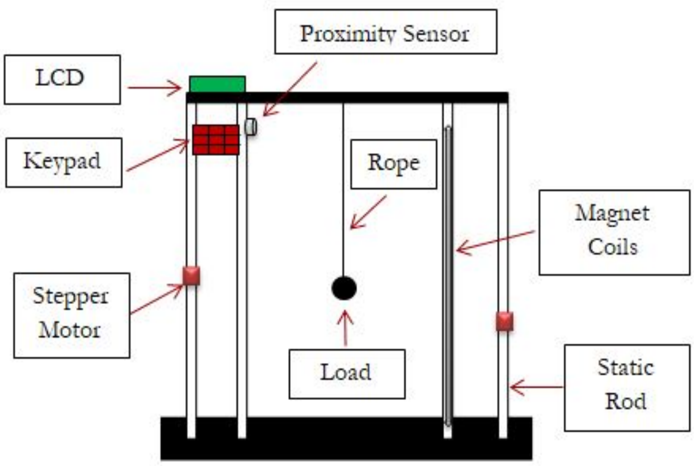

Figure 2. Mechanical Design of Mathematical Pendulum Experiment Modeling Tool

The mechanical design of the proximity sensor-based mathematical pendulum experiment modeling tool is as shown in Figure 2. The stepper motor unrolls the rope based on the rope length inputted on the keypad. The load at the starting point on the magnetic coil will be released automatically so that the load oscillates. Then when the object oscillates the proximity sensor will determine the time, period, frequency, and gravitational acceleration of the load. The frequency, period, time, and acceleration of the earth's gravity will be displayed on the LCD.

The performance of the mechanics depends on the performance of the software. The software design serves as an instruction to run the Arduino Uno microcontroller. The instructions given are in the form of rope length and many oscillations that will be processed by Arduino Uno. Programming aims to make the system on the mathematical pendulum modeling tool work well. The software design can be seen in Figure 3.

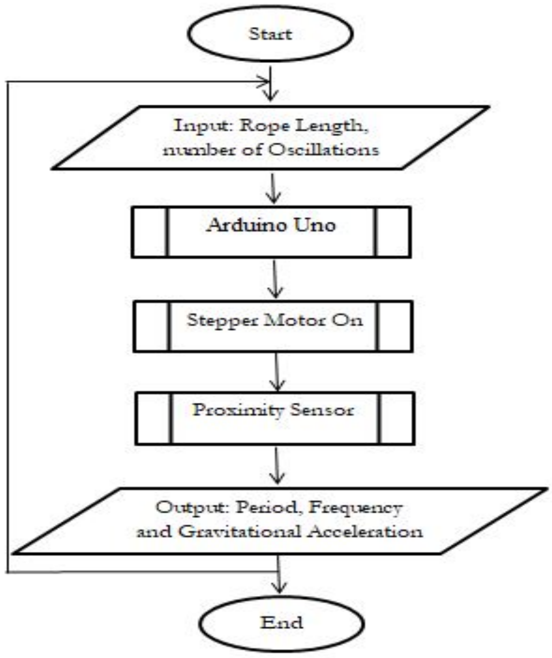

Figure 3. Software design

The software design used in the proximity sensor-based mathematical pendulum modeling tool can be seen as Figure 3. The system work starts with the input signal will be entered through the keypad displayed on the LCD and will be processed by Arduino Uno. So that the stepper motor will move according to the inputted value. Furthermore, the load that is pulled forms a deviation angle of θ and will oscillate when released by pressing the button on the keypad. Then the proximity sensor will determine the period, frequency, gravitational acceleration and oscillation time of the mathematical pendulum. The data obtained will be displayed on the LCD.

The simple harmonic motion that occurs in the mathematical pendulum is then recorded using a camera. During the recording process, the camera must be fixed and not shaky. To obtain this condition, a tripod can be used. The camera must be positioned parallel to the mathematical pendulum. The background must contrast with the modeling tool so that the simple harmonic motion that occurs is clearly visible. The video recording is then analyzed using a PC that has tracker software installed.

3. Results and Discussion

Based on literature studies and research that has been done, a mathematical pendulum modeling tool based on proximity sensors is produced. The results of this research are not much different from the design that the author has put forward. Through data processing, the relationship between the measured variables can be seen. Data analysis is carried out both in terms of measurement and the accuracy and precision of this experimental tool. Presentation of the data obtained will be displayed in tabular form and in graphical form.

3.1 Research Result

3.1.11 Results of Display Analysis on Tracker Software

After taking measurements by recording the practicum video, an overview was obtained when taking data or conducting experiments with a mathematical pendulum. Measurements were made with 2 variations of rope length, namely 0.4 m and 0.5 m. The load used in this experiment has a mass of 0.05 kg of metal. The data obtained will then be analyzed in depth using tracker software to see the pendulum trajectory which will be displayed in the form of a graph plot. The tracker will analyze the video based on pixels and frame reference, so as to obtain data on the position of the object at each time interval. The display on the tracker software of the video analysis results with the parameter of position change on the x-axis using a rope length of 0.4 m as shown in Figure 4.

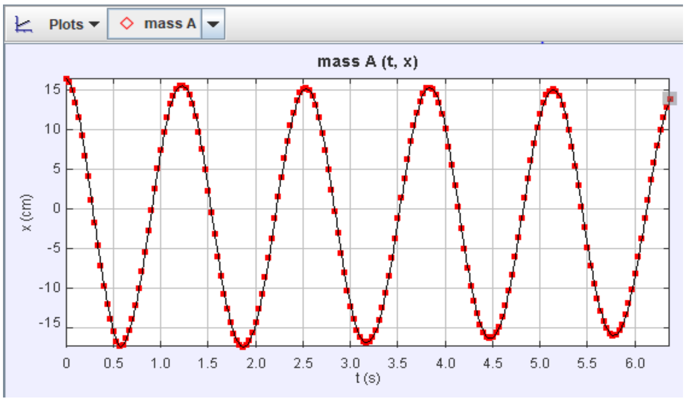

Figure 4. Change in Position on the X-axis

Figure 4 shows the graph of the relationship between the change in position and the oscillation time of the mathematical pendulum swing. The graph is obtained from 5 swings when taking measurements. From these physical quantities, a sinusoidal graph is obtained. Figure 4 shows the amplitude changes that are quite visible or significant. When the angular magnitude of the swinging pendulum decreases, the wave amplitude tends to be more stable. The data in Figure 13 shows oscillations with a rope length of 0.4 meters can be obtained oscillation amplitude seen ranging from -0.15 meters to +0.15 meters, indicating that the oscillations have a peak-to-peak amplitude of about 0.3 meters. From the analysis of the oscillation period, a period value of about 1.26 seconds is obtained, then the obtained period value is used to calculate the oscillation frequency of 0.79 Hz. From the available variable data, the value of gravitational acceleration is 9.88 m/s2. The display in the tracker software of the video analysis results with the parameter of speed change on the x-axis at a rope length of 0.4 m is shown in Figure 5.

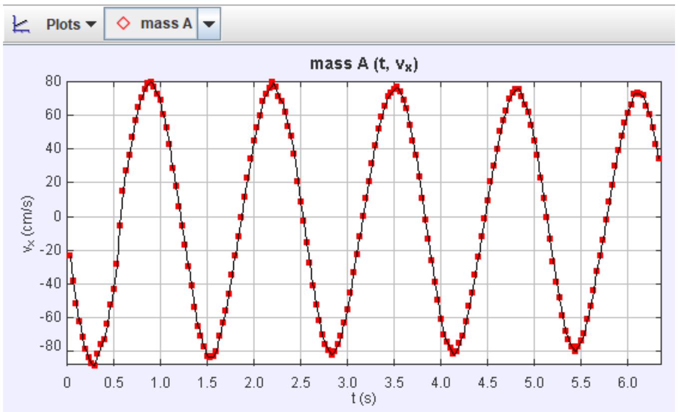

Figure 5. Change in Velocity at X-axis

Figure 5 is a graph of the relationship between oscillation speed and oscillation time. The graph is obtained from 5 swings when taking measurements. From these physical quantities, a sinusoidal graph is obtained. When the angular magnitude of the swinging pendulum decreases, the wave amplitude tends to be more stable. The data in Figure 5 shows oscillations with a rope length of 0.4 meters can be obtained oscillation amplitude seen ranging from -0.8 meters to +0.8 meters, indicating that the oscillation has a peak-to-peak amplitude of about 1.6 meters. From the analysis of the oscillation period, a period value of about 1.26 seconds is obtained, then the obtained period value is used to calculate the oscillation frequency of 0.79 Hz. From the available variable data, the value of gravitational acceleration is 9.88 m/s2. The velocity graph is obtained according to the theory where acceleration is the differential of the change in position.

3.1.12 Accuracy of the Mathematical Pendulum Modeling Tool

The accuracy of the mathematical pendulum modeling tool is obtained from comparing the test data obtained from the system measurement test results and video analysis using tracker software and then comparing it with the standard tool test data. Measurement of period, frequency, and acceleration of gravity in the modeling tool is measured using a proximity sensor. Data on the accuracy of period, frequency and acceleration of gravity measurements on the mathematical and theoretical pendulum modeling tool are shown in Table 1.

Table 1. Accuracy Analysis Data on Digital Display and Tracker

Data Type	Rope Length 0.4 meters		Accuracy (%)	Rope Length 0.5 meters		Accuracy (%)
	Display	Tracker		*Display*	Tracker	
T (s)	1.27	1.26	99.20	1.42	1.41	99.30
F (Hz)	0.79	0.79	100	0.70	0.71	98.57
g (m/s^2)	9.80	9.88	99.19	9.80	9.94	98.59

Based on the data in Table 1, it can be described that the data analysis of the measurement accuracy of the period, frequency, and acceleration of gravity in the mathematical pendulum modeling tool has good measurement accuracy. The accuracy of measurement data is obtained by comparing the data obtained on the digital display of the mathematical pendulum with the data obtained by video analysis using tracker software. Measurements were made with 2 variations of rope length, namely 0.4 meters and 0.5 meters. In the variation of rope length 0.4 meters, the accuracy value of the period is 99.21%, the accuracy value of the frequency is 100%, and the accuracy value of the acceleration of gravity is 99.19%. While in the variation of rope length 0.5 meters, the period accuracy value is 99.30%, the frequency accuracy value is 98.57%, and the acceleration value of gravity is 98.59%. From the accuracy data that is almost close to the 100% value, it can be indicated that the reading of the measurement value on the digital display of the mathematical pendulum is close to the value of the video analysis results using the tracker software. Data on the accuracy of period, frequency and gravitational acceleration measurements on the calculation of time (t) of the mathematical pendulum modeling tool and the calculation of time (t) of the stopwatch are shown in Table 2.

Table 2. Accuracy Analysis Data on Time Calculation (t) Modeling Tool and Time Calculation (t) Stopwatch

Data Type	Rope Length 0.4 meters		Accuracy (%)	Rope Length 0.5 meters		Accuracy (%)
	Tool	*Stopwatch*		*Tool*	*Stopwatch*	
T (s)	1.28	1.274	99.53	1.32	1.324	99.70
F (Hz)	0.78	0.785	99.36	0.757	0.755	99.74
g (m/s^2)	9.68	9.72	99.59	11.3	11.25	99.56

Based on the data in Table 2, it can be described that the measurement accuracy of the period, frequency, and acceleration of gravity on the mathematical pendulum modeling tool has good measurement accuracy. The accuracy of measurement data is obtained by comparing the data obtained in the calculation of time (t) of the modeling tool with the data obtained by calculating time (t) on a standard measuring instrument, namely a stopwatch. Measurements were made with 2 variations of rope length, namely 0.4 meters and 0.5 meters. In the variation of the rope length of 0.4 meters, the accuracy value of the period is 99.53%, the accuracy value of the frequency is 99.36%, and the acceleration value of gravity is 99.59%. Whereas in the variation of rope length 0.5 meters, the accuracy value of period is 99.70%, the accuracy value of frequency is 99.74%, and the acceleration value of gravity is 99.56%. From the accuracy data that is almost close to the 100% value, it can be indicated that the calculation of time (t) on the modeling tool is close to the value of the calculation of time (t) on standard measuring instruments.

3.1.13 Precision of the Mathematical Pendulum Modeling Tool

The Precision of the mathematical pendulum is obtained from repeated measurements on the modeling tool by varying the length of the rope used. Measurements on the pendulum were carried out with two variations of rope length, namely 0.4 meters and 0.5 meters with oscillations 5 times for each rope length. In the measurement of period, frequency, and acceleration of gravity, repeated measurements are made 5 times for each length of rope. The following is the data analysis of the Precision of the period, frequency and acceleration of gravity in the modeling tool.

Table. 3 Precision Analysis Data on Mathematical Pendulum Modeling Tool Rope Length 0.4 M

No	T (s)	Precision (%)	f (Hz)	Precision (%)	g (m/s^2)	Precision (%)
1	1.27	99.92	0.79	99.49	9.80	99.88
2	1.26	99.15	0.79	99.49	9.93	98.57
3	1.28	99.29	0.78	99.24	9.73	99.39
4	1.274	99.76	0.785	99.87	9.72	99.28
5	1.272	99.94	0.786	100	9.75	99.59
$\bar{x}$	**1.271**	**99.61**	**0.786**	**99.62**	**9.79**	**99.34**

Based on the data in Table 3, it can be stated that the measurement precision data of period, frequency, and gravitational acceleration on the mathematical pendulum modeling tool have quite good precision. The frequency measurement results on the mathematical pendulum swing modeling tool have a high percentage of precision compared to measurements on the period and acceleration of gravity. In the period data, the precision value is 99.61%. The precision of the frequency data is 99.62%. The precision of the gravity acceleration data is 99.34%. From the results of the calculation of the precision of mathematical pendulum measurements on the modeling tool taken using a proximity sensor. The results of the calculation of the precision of the period, frequency, and acceleration of gravity data in the experiment have the value of the analysis results almost close to the perfect value so that the period, frequency and acceleration of gravity in the modeling tool are accurate.

Table. 4 Precision Analysis Data on Mathematical Pendulum Modeling Tool Rope Length 0.5 M

No	T (s)	Precision (%)	f (Hz)	Precision (%)	g (m/s^2)	Precision (%)
1	1.42	97.10	0.70	95.50	9.80	93.33
2	1.41	97.82	0.70	95.50	9.91	96.21
3	1.40	98.55	0.757	96.73	10.3	98.10
4	1.324	95.94	0.755	96.99	11.25	92.86
5	1.325	96.02	0.754	97.14	11.24	92.95
$\bar{x}$	**1.38**	**97.09**	**0.733**	**96.37**	**10.5**	**94.70**

Based on the data in Table 4, it can be explained that the precision of the measurement data of the period, frequency, and acceleration of gravity on the mathematical pendulum modeling tool has quite good precision. The period measurement results on the mathematical pendulum swing modeling tool have a high percentage of precision compared to measurements on frequency and acceleration of gravity. In the period data, the precision value is 97.09%. The precision of the frequency data is 96.37%. The precision of the gravity acceleration data is 94.70%. From the results of the calculation of the accuracy of mathematical pendulum measurements on the modeling tool taken using a proximity sensor. The results of the calculation of the precision of the period, frequency, and acceleration of gravity data in the experiment have the value of the analysis results almost close to the perfect value so that the period, frequency and acceleration of gravity in the modeling tool are accurate.

3.1.14 Effect of Rope Length on Period and Frequency

The use of rope length greatly affects the oscillations that occur in mathematical pendulum swings. The use of a rope that is too short results in no simple harmonic motion on the mathematical pendulum. Meanwhile, the use of a rope that is too long results in rotary swing. Experiments have been conducted on a mathematical pendulum with 4 variations in rope length with 5 oscillations. The following is data on the effect of rope length on the period and frequency of the mathematical pendulum experiment as shown in Table 5.

Tabel 5. Effect of Rope Length on Period and Frequency

No	L (m)	F (Hz)	T (s)	g (m/s^2)
1	0.2	1.11	0.89	9.96
2	0.3	0.91	1.09	9.95
3	0.4	0.79	1.26	9.93
4	0.5	0.70	1.41	9.91
	Rata-rata	**0.88**	**1.16**	**9.94**

Based on the data in Table 5, the results of measurements with 4 variations in rope length obtained several physical quantities including period, frequency, and gravitational acceleration. From the results of data analysis, the average frequency is 0.88 Hz, the average period is 1.16 seconds, and the average acceleration of gravity is 9.94 m/s2. Based on the analysis conducted, it is obtained that the period value will get bigger along with the use of longer ropes. Meanwhile, the frequency value will get smaller as the rope gets longer. The magnitude of the period value does not depend on the mass, so we can conclude that all simple pendulums with the same rope length and at the same location will oscillate with the same period.

4. Conclusion

The results of the accuracy and precision test of the development of the proximity sensor-based mathematical pendulum swing experiment modeling tool for video tracker analysis are the average error and relative accuracy of the period of 0.74% and 99.25%, frequency of 1.42% and 99.28% and acceleration of gravity of 1.12% and 98. 89% for the comparison of values on the digital display of the mathematical pendulum and tracker analysis, as well as the average error and relative accuracy of the period of 0.385% and 99.62%, frequency of 0.45% and 99.55% and acceleration of gravity of 0.47% and 99.09% for comparison of the calculation value of t tool modeling and t standard measuring instrument (stopwatch). As for the average value of the accuracy of period measurement data obtained by 99.61%, frequency by 99.62% and acceleration of gravity by 99.34% for a rope length of 0.4 meters, the average value of the accuracy of period measurement data obtained by 97.09%, frequency by 96.37% and acceleration of gravity by 94.70% for a rope length of 0.5 meters. From the data analysis, the accuracy and precision of the mathematical pendulum modeling tool has quite good accuracy and precision. The weakness or shortcoming of the development of this proximity sensor-based mathematical pendulum experiment modeling tool is the limited number of rope length variations. The rope length variation in the mathematical pendulum modeling tool is 4 rope length variations.

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